PRODUCTION OF CARBON-14 IN MARTIAN SOIL NITROGEN. J. Masarik[1] and R. C. Reedy[2], [1]Dept. of Nuclear Physics, Komensky Univ., SK-84215 Bratislava, Slovakia; presently at EAWAG, CH-8600 Dübendorf, Switzerland, [2]Los Alamos National Laboratory, Group NIS-2, MS D436, Los Alamos, NM 87545 USA.

The 5730-year radionuclide carbon-14 (^{14}C) produced in the Martian atmosphere can be used to study atmosphere-regolith interactions, where $^{14}CO_2$ serves as the tracer [1]. However, the calculations in [1] only considered production of ^{14}C in nitrogen and oxygen in the Martian atmosphere and in oxygen in the Martian surface but did not consider production in any nitrogen in Martian soil. While the abundance of N in the Martian surface is not known, production of ^{14}C from soil N could be the dominant source of Martian ^{14}C. Production rates of ^{14}C in a Martian soil with 1 percent by weight of nitrogen are reported here.

The same set of computer codes as used in [1], the LAHET Code System (LCS), was used for numerically simulating the interaction of galactic cosmic rays (GCR) particles with Mars and the production and transport of secondary neutrons. LCS has been tested for many calculations involving the production of cosmic-ray-produced (cosmogenic) nuclides in meteorites and lunar samples [e.g., 2]. LCS was also used to study the production of gamma rays in Mars by GCR secondary neutrons [3].

The GCR particles are ~87% protons, have very high energies, make many secondary particles, especially neutrons, and penetrate to great depths. The calculations for GCR interactions in Mars were done the same as for the production of 14C in the Martian atmosphere [1] and for the production of gamma rays in Mars [3].

The same composition was used for the Martian atmosphere, although only an atmospheric thickness of 15 g/cm^2 was used. The composition of the soil was the same as used previously [1,3] with a soil water content of 1%, except that the elemental concentrations were adjusted so that the soil contained 1 % nitrogen by weight. The major elements in this Martian soil (and their concentrations in weight percents) were C (0.6), O (46.1), Na (0.8), Mg (3.66), Al (4.06), Si (21.3), S (3.0), Cl (0.7), Ca (4.36), and Fe (13.4).

The concentration of nitrogen, or of its compounds (most likely nitrates, NO_3), in Martian soil is not known. Analyses of the Elephant Moraine A79001 shergottite and Nakhla by [4] indicated only low abundances of nitrates. Some nitrogen (N_2) could also be adsorbed on Martian soil [5]. Thus the abundance of nitrogen in Martian soil is unknown, and the 1% value used for the concentration of elemental N is arbitrary.

The production of ^{14}C by neutron-capture reactions with ^{14}N was calculated using the MCNP code in LCS, the same as done in [1] for ^{14}C production from N in the Martian atmosphere. The production rate of ^{14}C calculated for Martian soil with 1%N is shown in Fig. 1.

A concentration of 1% N in Martian soil captures 7.2% of the low-energy neutrons, although only 6.9% of captured neutrons make ^{14}C (with the rest of the neutrons captured by N making ^{15}N). This capture fraction for N in Martian soil is less than the 87% for neutron capture by N in the Martian atmosphere. The greater flux of low-energy neutrons in Martian soil and the greater thickness of the soil results in a larger total production rate for ^{14}C in this soil than in the Martian atmosphere.

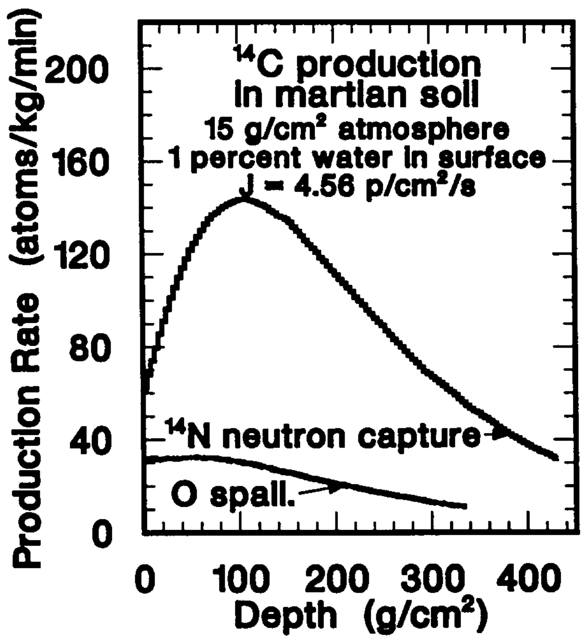

Fig. 1. Production rate of ^{14}C as a function of depth for neutron capture on 1% N and spallation on oxygen as a function of depth in the Martian surface.

The production rate of ^{14}C by neutron-capture by N decreases with an e-folding length of 172 g/cm^2 for the deepest depths calculated here. Using this e-folding length for depths below 432 g/cm^2, the total production of ^{14}C in this Martian soil with 1% N is 45.3 atoms/cm^2/min, with 39.8 of it between the surface and a depth of 432 g/cm^2. For depth intervals of 0-100, 100-200, 200-300, and 300-400 g/cm^2, the ^{14}C production rates are 11.4, 13.2, 8.9, and 5.2 atoms/cm^2/min, respectively.

The production of ^{14}C by spallation reactions on Martian soil oxygen is 9.8 atoms/cm^2/min, for a total soil ^{14}C production of 55 atoms/cm^2/min.

These production rates for ^{14}C from soil N need to be compared with those previously calculated by [1] for the Martian atmosphere, 1.4 atoms/cm^2/min. Thus ^{14}C made in the Martian atmosphere is only 3% of that made in Martian soil with 1% nitrogen. The loss of only a few percent of the ^{14}C in a N-rich soil would dominate ^{14}C in Mars.

Two important questions need to be answered before one needs to take the above calculations seriously as affecting the Martian ^{14}C atmospheric inventory. The first is whether

1% N is a reasonable value for Martian soil both globally and to a depth of the order of a meter. The second question is whether ^{14}C made in such soils would escape into the atmosphere.

The content of N in Martian soil is not known, but some soil nitrogen is possible. The Viking landers were not able to measure C or N. The sum of the elements heavier than Na (Mg through Fe) measured by Viking landers, assuming that they are oxides, is only about 0.90 [6]. Using the composition of SNC meteorites for some minor elements [7], the sum becomes 91.4%. It is possible that 1% N (4.4% NO_3) could be part of the missing elements in the Viking lander soil analyses. Analyses of samples of the SNC meteorites give low abundances of N [e.g., 4], although this might be more representative of Martian rocks than Martian soil.

In most silicate minerals found in meteorites or lunar samples, cosmogenic ^{14}C is not lost. Loss of ^{14}C is generally not expected as carbon is retained much better than noble-gas elements like helium and neon and only a few minerals lose cosmogenic He. However, the nature of Martian N is not known, so it is not obvious that ^{14}C made in Martian soil nitrogen will not be lost.

While ^{14}C in a returned sample of Martian atmosphere should be a good indicator of atmosphere-regolith interactions [1], the high calculated production rate of ^{14}C in Martian soil with 1% nitrogen means that the nitrogen content of Martian soil needs to be determined and the nature of that nitrogen, especially whether ^{14}C could escape, also needs to be considered.

References: [1] Jakosky B.M., Reedy R.C. and Masarik J. (1996) J. Geophys. Res. 101, 2247-2252. [2] Masarik J. and Reedy R.C. (1994) Geochim. Cosmochim Acta 58, 5307-5317. [3] Masarik J. and Reedy R.C. (1996) J. Geophys. Res. 101, 18891-18912. [4] Grady M.M., Wright I.P., and Pillinger C.T. (1995) J. Geophys. Res. 100, 5449-5455. [5] Zent A.P., Quinn R.C., and Jakosky B.M. (1994) Icarus 112, 537-540. [6] Clark B.C. et al. (1982) J. Geophys. Res. 87, 10059-10067. [7] Banin A., Clark B.C., and WŠnke H. (1992) in Mars (Univ. Ariz. Press), pp. 594-625. *We thank Bruce Jakosky and Tim Jull for many discussions on this subject. The work at Los Alamos was supported by NASA and done under the auspices of the U.S. Department of Energy.